Environmental and Mechanical Stability of Environmental Barrier Coated SA Tyrannohex SiC Composites under Simulated Turbine Engine Environments

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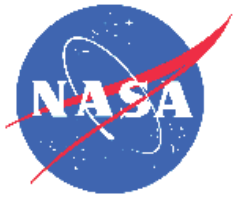

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Abstract

The environmental stability and thermal gradient cyclic durability performance of SA Tyrannohex composites were investigated for turbine engine component applications. The work has been focused on investigating the combustion rig recession, cyclic thermal stress resistance and thermomechanical low cycle fatigue of uncoated and environmental barrier coated Tyrannohex SiC SA composites in simulated turbine engine combustion water vapor, thermal gradients, and mechanical loading conditions. Flexural strength degradations have been evaluated, and the upper limits of operating temperature conditions for the SA composite material systems are discussed based on the experimental results.

Acknowledgement

The work was supported by NASA Fundamental Aeronautics Program Aeronautical Sciences Project.

Objectives

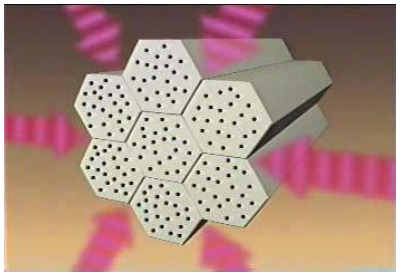
- **Evaluate a commercial SA-Tyrannohex composite (Ube, Japan) stability potentially for airfoil applications, due to its excellent high temperature mechanical and thermal properties**
  - Combustion environment recession rates tested at 2500°F (1371°C) under high velocity (200 m/s)
  - Compare with other SiC/SiC composites and Si_3N_4 ceramics

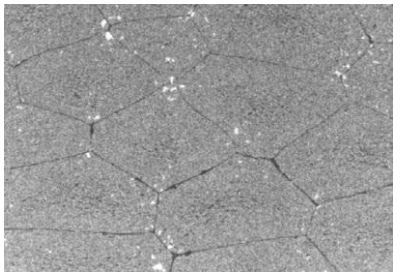
- **Determine thermal cyclic stability especially under high thermal gradients**
  - Effect of coating thickness

- **Evaluate Environmental barrier coating (EBC) coated Tyrannohex-SA composite stability and durability**
  - Long-term flexural fatigue evaluations under high heat flux laser rig at temperatures up to 2700°F

- **Summary**

SA-Tyrannohex

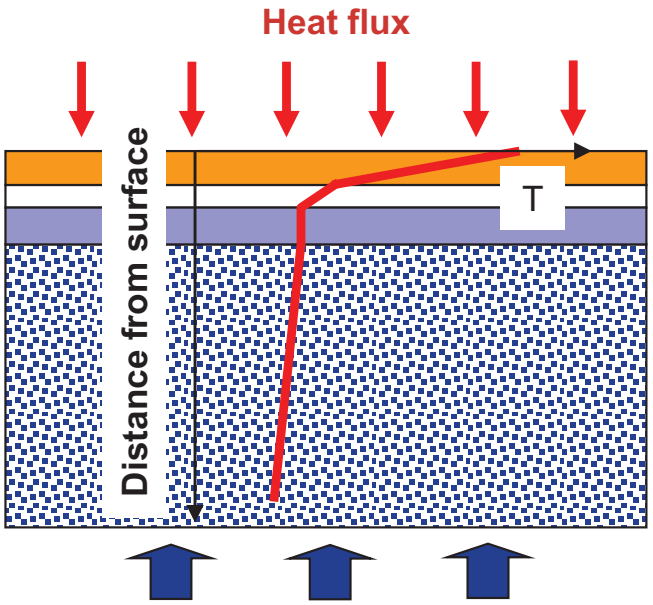




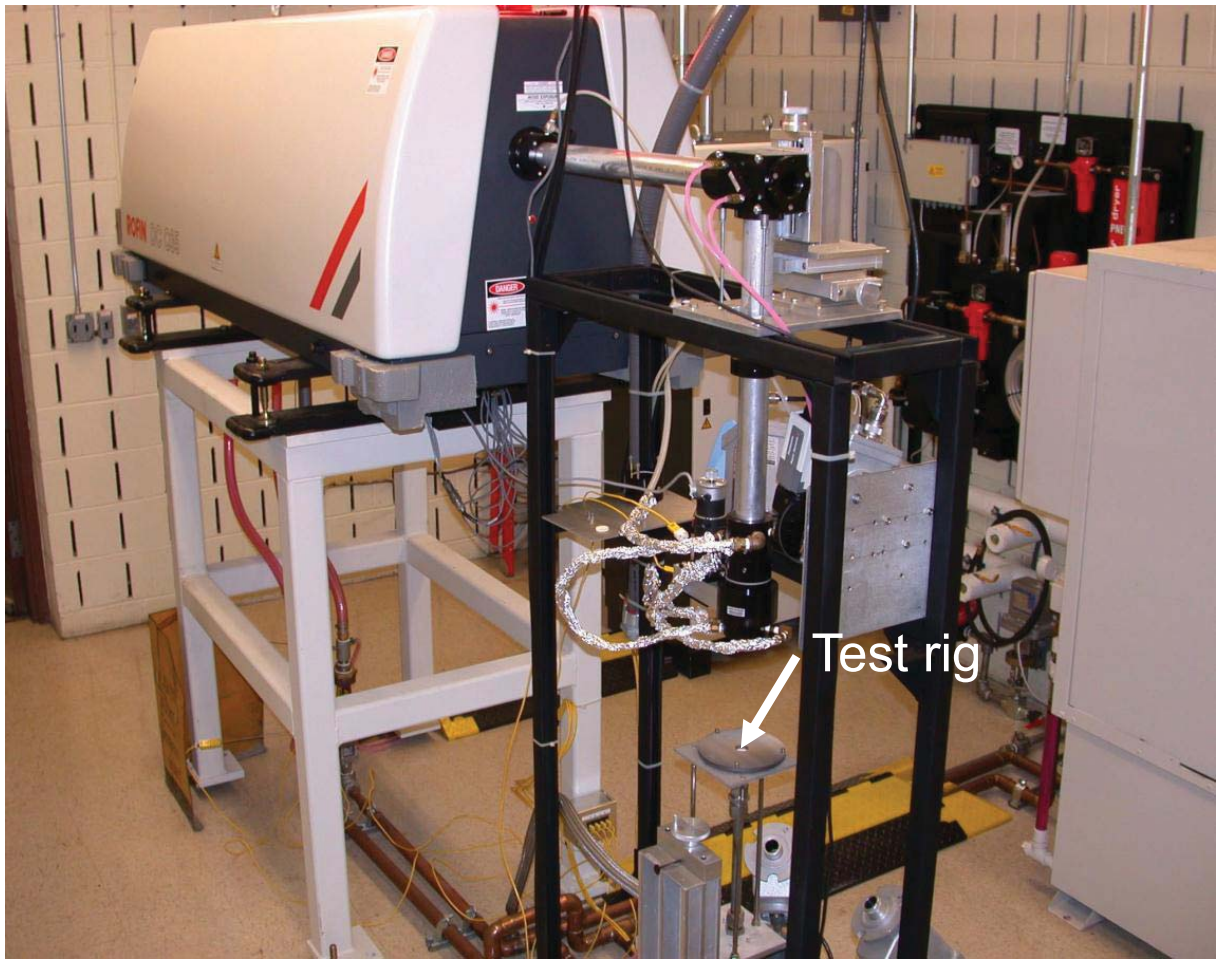
High Heat Flux CO_2 Laser Rig For Thermal Gradient Cycling Stability Evaluations

– High heat flux CO_2 laser rig tested two configurations of SA-Tyrannohex 25x25x10 mm and 25x25x3 mm for thermal gradient and cyclic durability

Turbine: 450°F across 100 microns
Combustor:1250°F across 400 microns



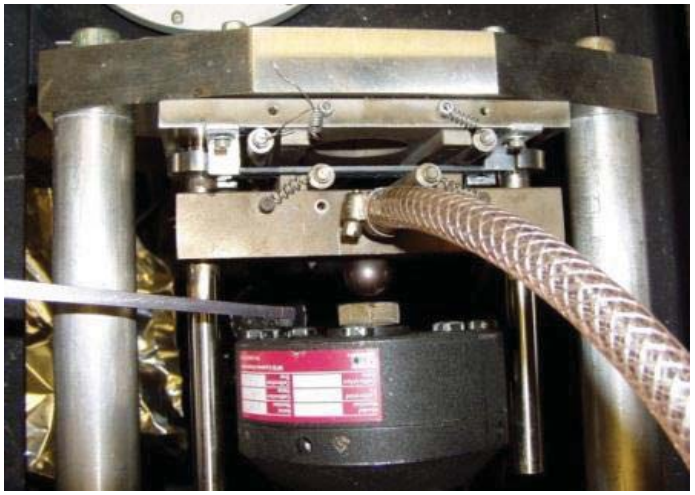
Cooling – high velocity air or air-water mist
Achieved heat transfer coefficient 0.3 W/cm²-K

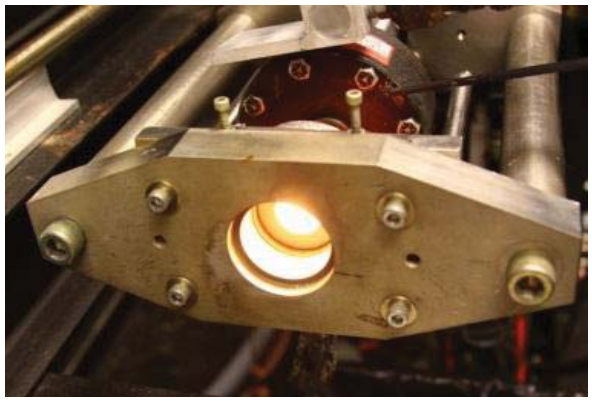


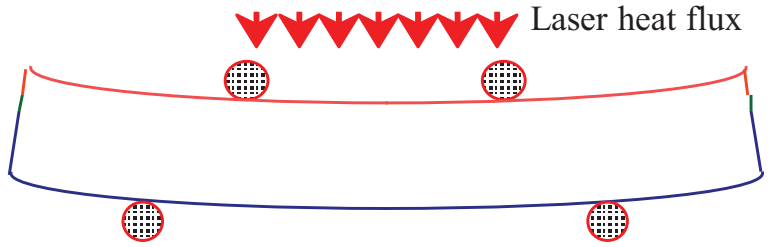
(a) High heat flux cycling test rig

High Heat Flux CO_2 Laser Bend Fatigue Rig For Simulated Thermal Gradient Fatigue Resistance Evaluations

– High heat flux CO_2 laser bend fatigue rig tested SA-Tyrannohex for thermo-mechanical durability: specimen configuration 76x12.7x3 mm



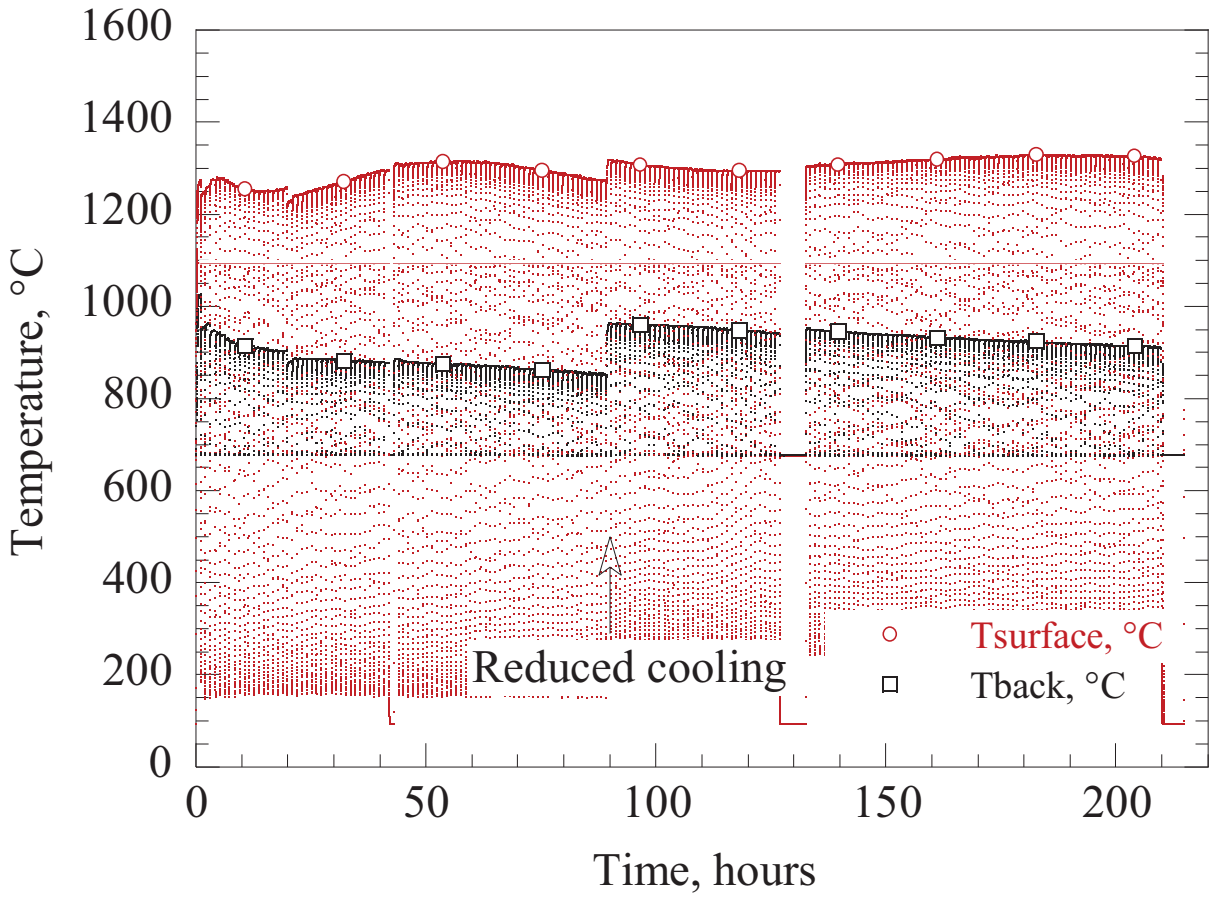




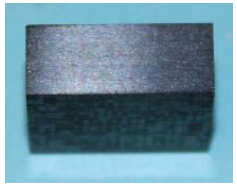
(b) High heat flux flexural fatigue test rig

SA Tyrannohex Ceramic Specimen Tested Under Cyclic Heat Flux Thermal Gradients

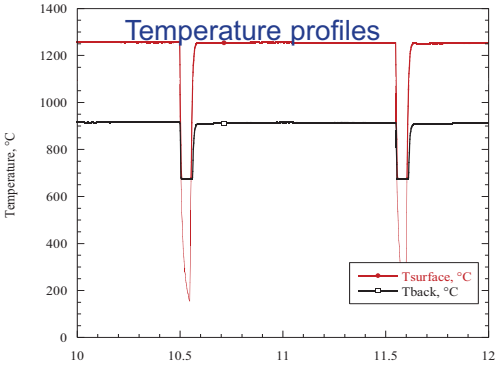
- SA Tyrannohex 25x25x10 mm specimen tested at under turbine thermal gradient cycling conditions: Tsurface 2300-2400°F (1260-1316°C), Tback 1700-1750°F (927-954°C), 1 hr cyclic in air, for total 195 cycles
- Late stage testing (after ~110 cycles) showed specimen delamination (increased surface temperature and reduced back temperature with cycling under heat flux)

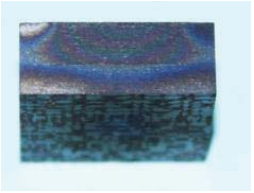


Specimen under testing

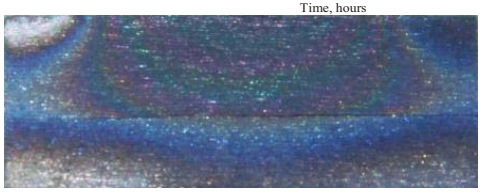


As received specimen-sideview



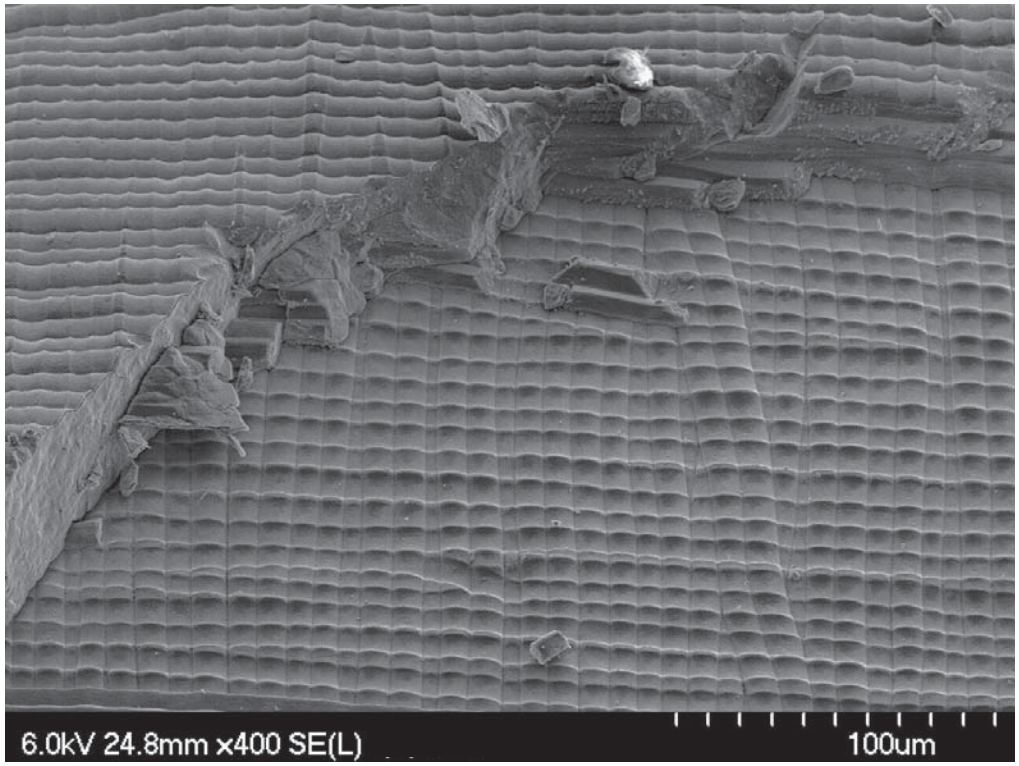


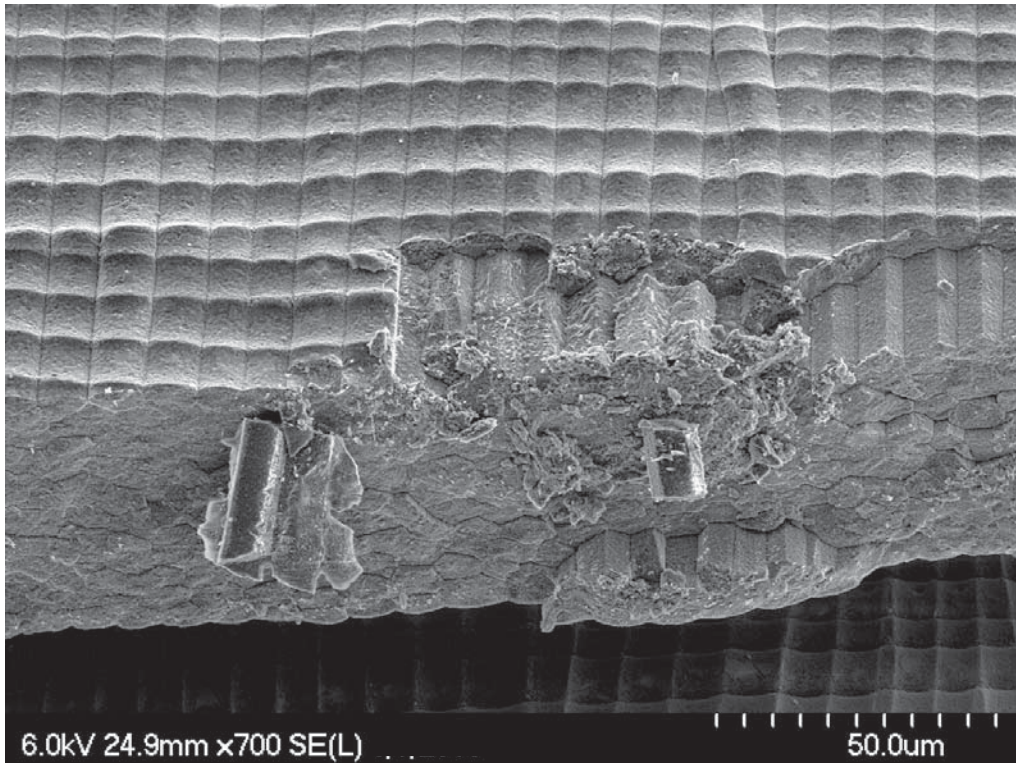
After 195 hr testing specimen - sideview



SA Tyrannohex Ceramic Specimen Tested Under Cyclic Heat Flux Thermal Gradients - Continued

- SA Tyrannohex 25x25x10 mm specimen tested at under turbine thermal gradient cycling conditions: Tsurface 2300-2400°F (1260-1316°C), Tback 1700-1750°F (927-954°C), 1 hr cyclic in air, for total 195 cycles
- Late stage testing (after ~110 cycles) showed specimen delamination (increased surface temperature and reduced back temperature with cycling under heat flux)

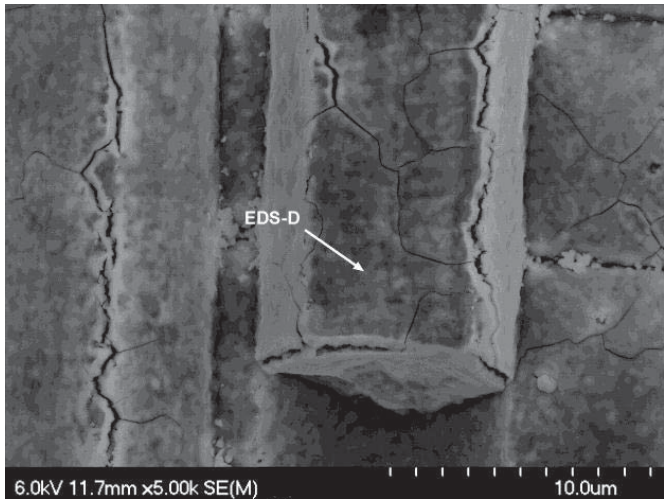


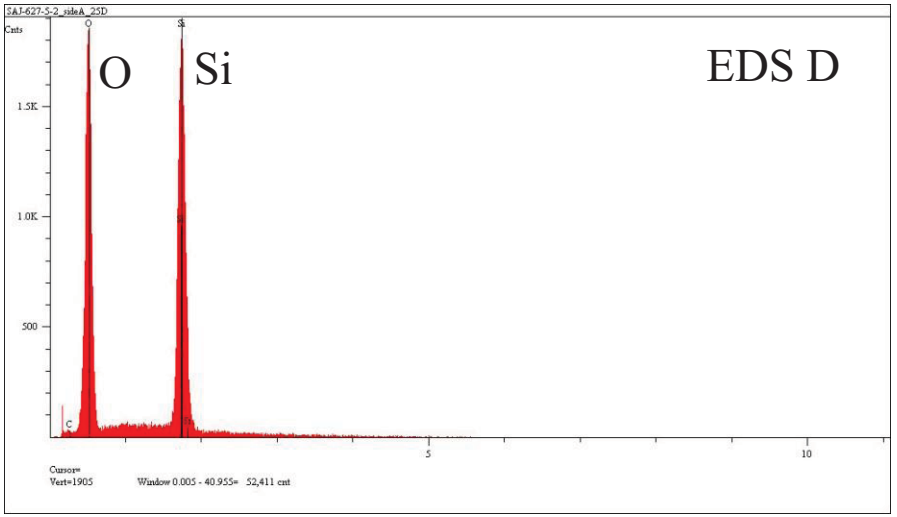


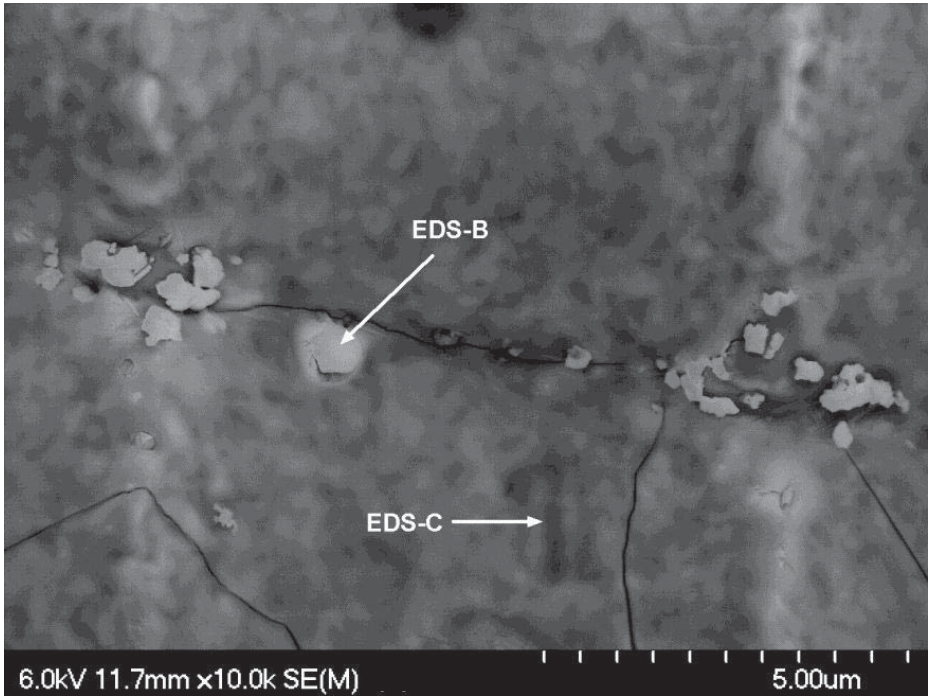
Failed specimen delamination surfaces

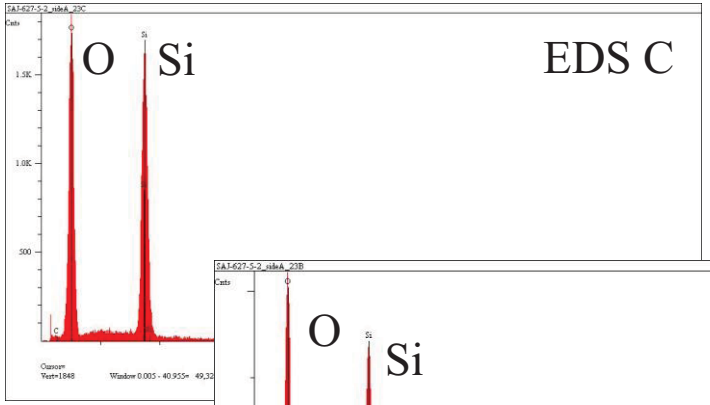
SA Tyrannohex Ceramic Specimen Tested Under Cyclic Heat Flux Thermal Gradients - Continued

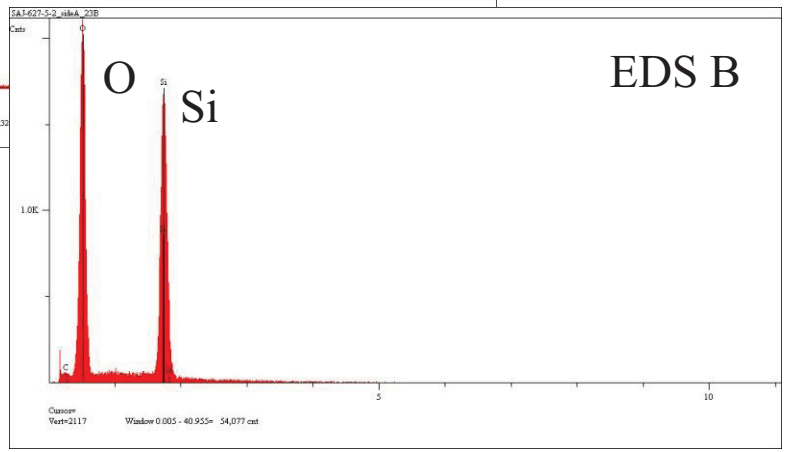
- Severe oxidation was found also to be detrimental to durability





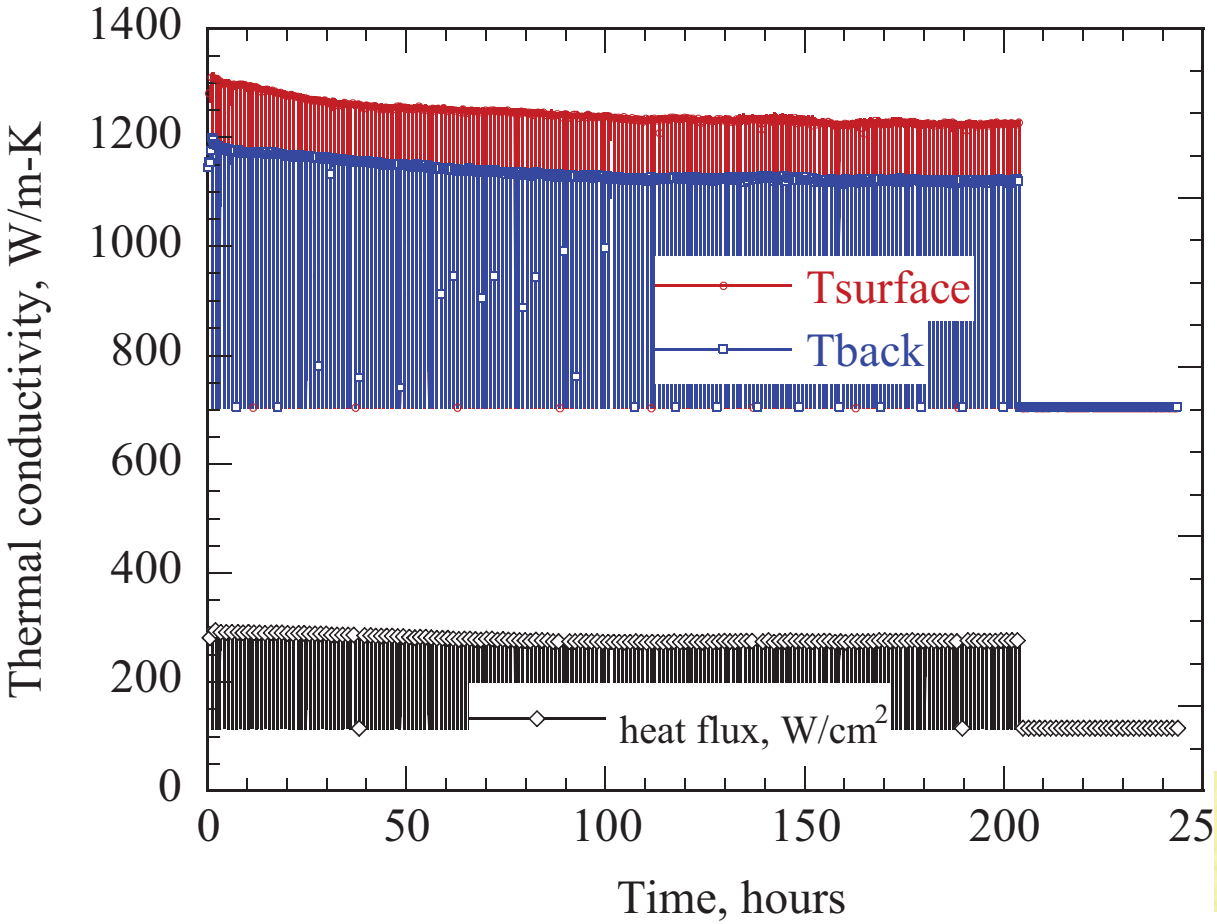






SA Tyrannohex Ceramic Specimen Tested Under Cyclic Heat Flux Thermal Gradients

- SA Tyrannohex 25x25x3 mm specimen tested at under turbine thermal gradient cycling conditions: Tsurface 2300-2400°F (1260-1316°C), Tback 1700-1750°F (900°C), 1 hr cyclic in air, for total 200 cycles
- No major delamination under the thin specimen configuration possibly due to less complex temperature profiles; minor “micro” level delamination cracking and specimen size increase possibly due to oxidation

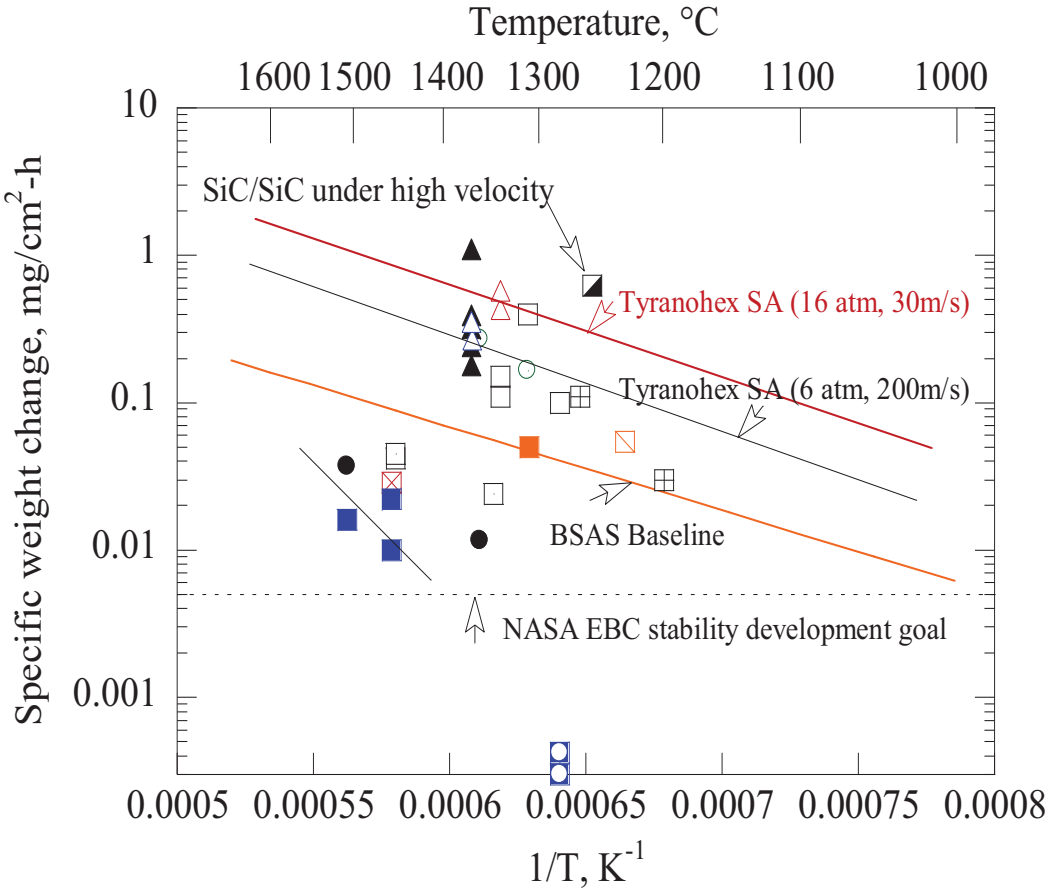


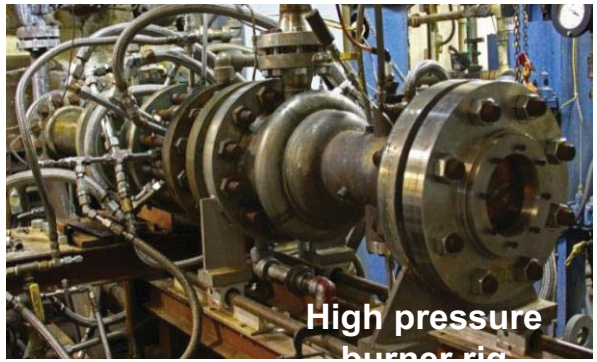
As-received specimen (cross-section view)

Tested specimen (cross-section view)

SA Tyrannohex SiC Ceramic Composites Recession Rates Tested at Various Conditions

- Recession rates of Tyraonnohex SA SiC composite tested at 1340 – 1371°C all at 200 m/s gas velocity in High Pressure Burner rig
- The stability is in-line with other silicon based materials
- Unlabeled comparison specimen test conditions are standard condition, 6 atm 30 m/s

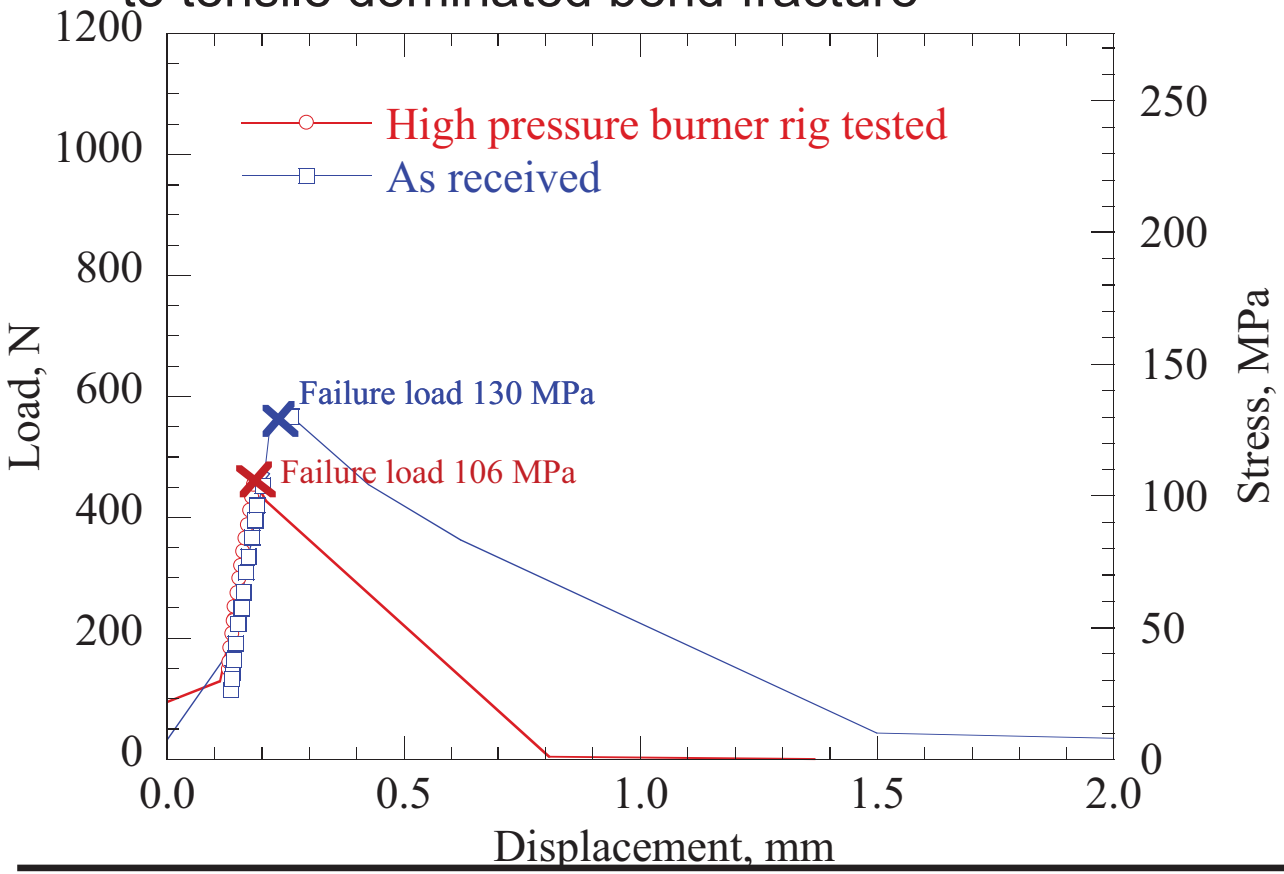


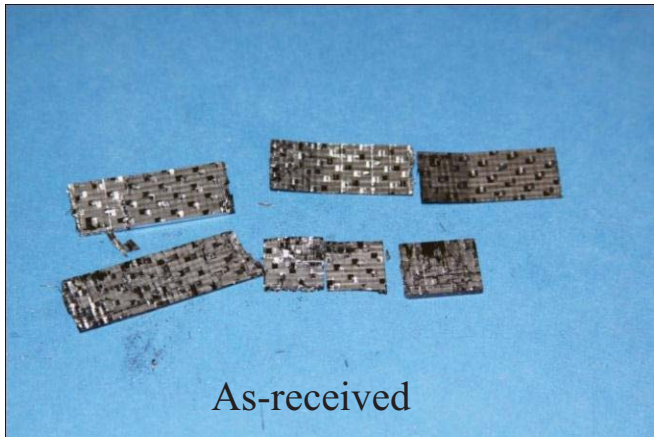


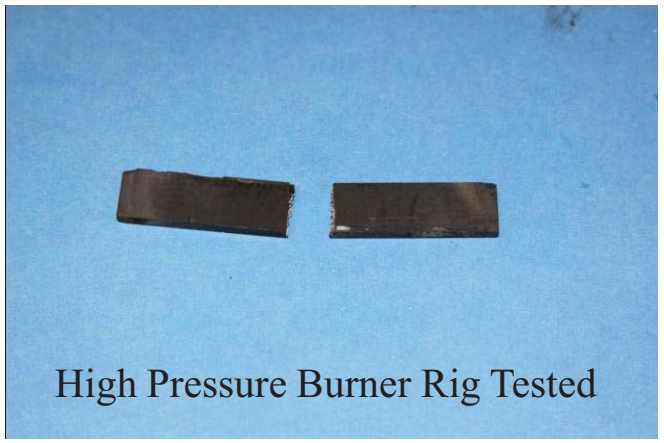
BSAS baseline
SiC/SIC CMC
AS800
SN282
BSAS
La2Hf2O7
HfO2 (doped)
HfRE Aluminosilicate
Yb-Silicate
SiC/SiC CMC (200 m/s)
Tyranohex SA SiC composite (200m/s)
BSAS (200m/s)
HfO2-1 (200 m/s)
Goal
Tyranohex SA SiC composite (6 atm, 200m/s)
Tyranohex SA SiC composite (16atm, 200m/s)

SA Tyrannohex Composite Flexural Strength

- Flexural test strength tests of High Pressure Burner Rig Tested at 2500°F (1371°C) for 20 hours and as received Tyrannohex SA composite specimens, and the two specimen failed at critical stresses of 130 and 106 MPa, respectively
- Slightly reduced strength observed after the burner rig test. The failure mode changed from the composite shear delamination for the as–received specimen to tensile dominated bend fracture

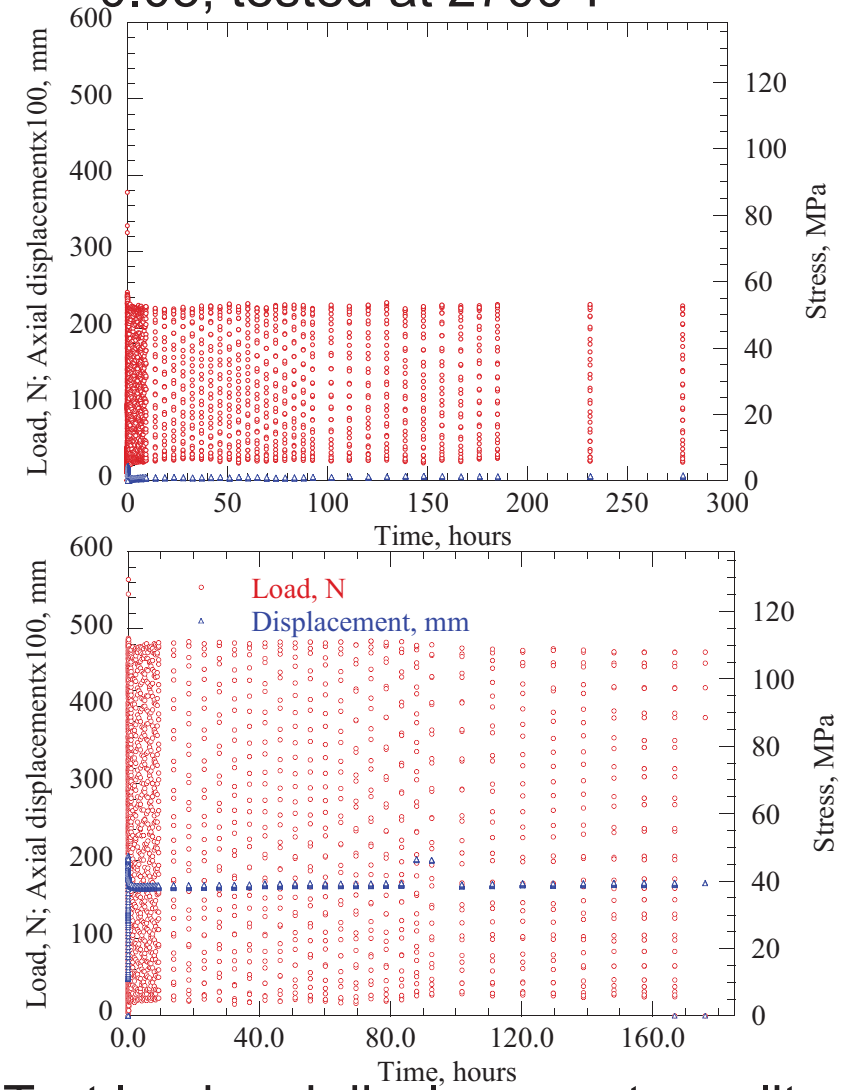




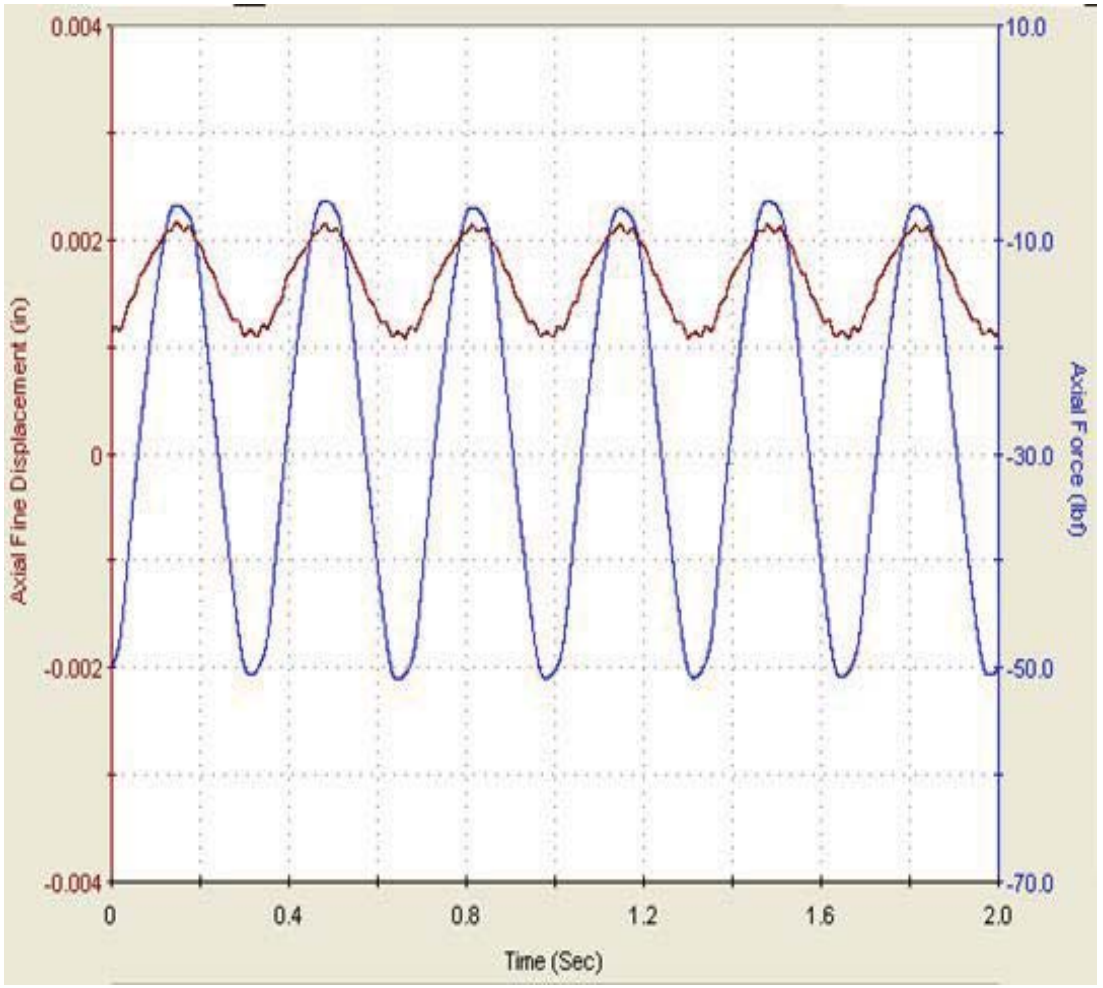


High Temperature Long-Term Thermomechanical Fatigue Testing of SA Tyrannohex SiC Composites with Advanced 2700°EBCs

– Step load increases for testing up to 15 Ksi; frequency 3 Hz and stress ratio 0.05, tested at 2700°F



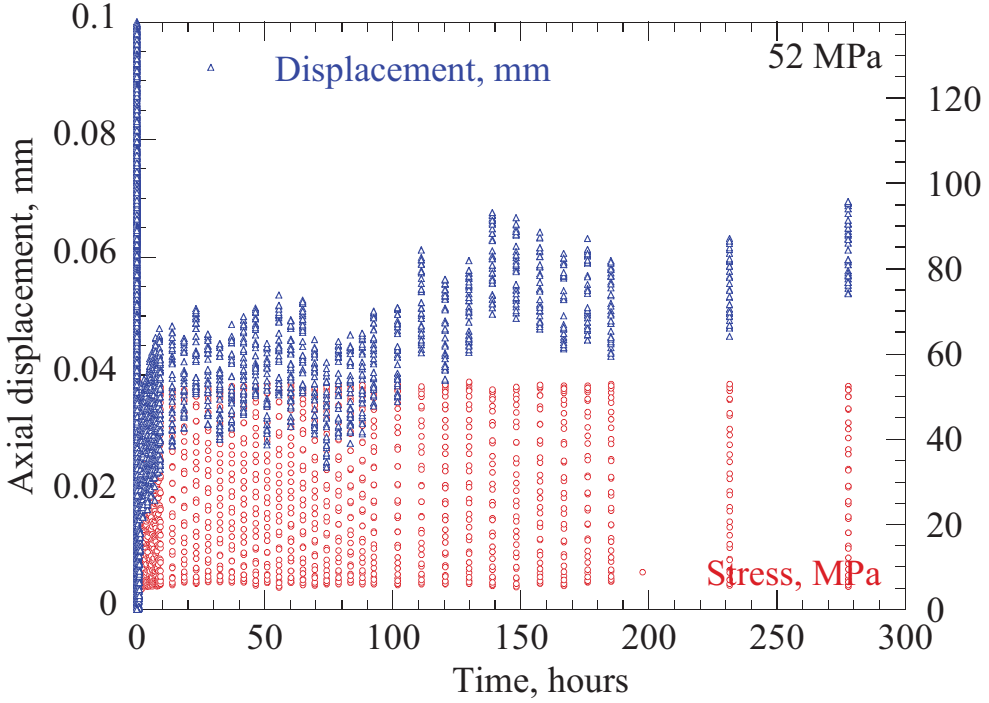
Test load and displacement amplitudes

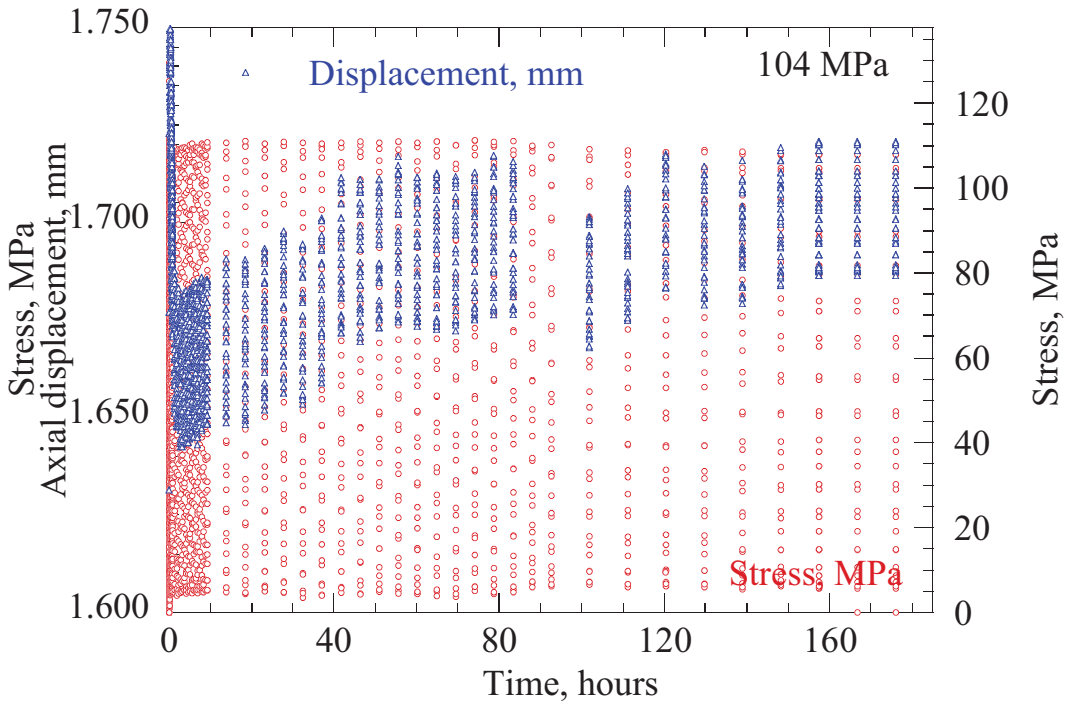


Wave form, 3 Hz fatigue cycles

High Temperature Long-Term Thermomechanical Fatigue Testing of SA Tyrannohex SiC Composites with Advanced 2700°EBCs

- The fatigue cycles at 52 MPa (tested 3 million cycles) and 104 MPa (tested 2 million cycles), measured total creep strains 0.035% at the 52 MPa and 0.06% at 104 MPa, respectively, derived from the displacement measurements

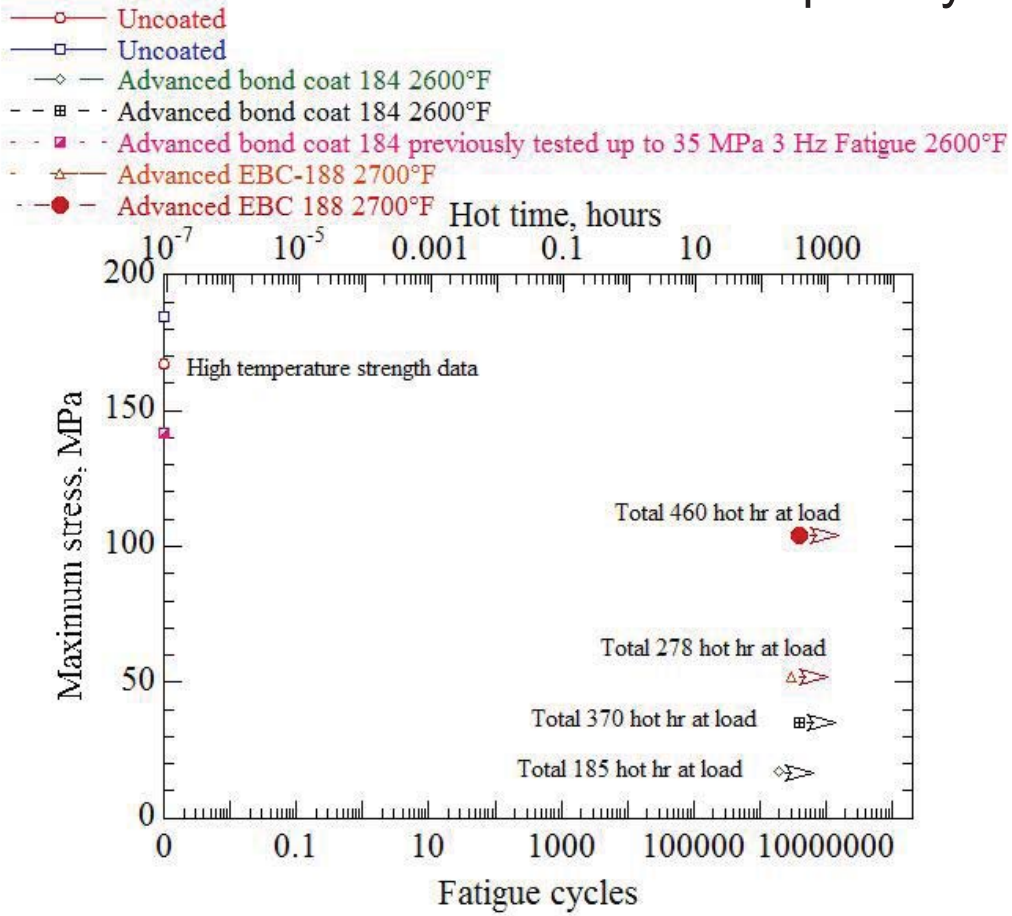




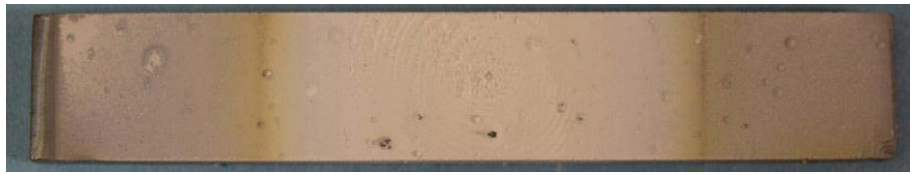
Displacement and Stress amplitudes

High Temperature Long-Term Thermomechanical Fatigue Behavior of Advanced 2700°F EBC Coated SA Tyrannohex Composites

- Advanced turbine environmental barrier coatings developed suitable for the SA Tyrannohex composites
- The coating showed excellent performance with the SA systems
- Long-term fatigue lives (near 500 hr) achieved at 2700°F under loading at 15Ksi
- Demonstrated 2700°F EBC capability



Tested, SA Tyrannohex with bond coat only



Tested, SA Tyrannohex with EBC system 188

Summary

- Environmental stability and thermal gradient cyclic durability performance of SA Tyrannohex composites investigated under very harsh simulated combustion and heat flux thermo-mechanical conditions

- The material showed good combustion environment resistance at 2500° F; the recession rates are generally expected in line with major advanced SiC or Si_3N_4 systems, but the composite material is capable of the higher testing temperatures

- SA Tyrannohex tends to delaminate in the as-processed condition, some pre-oxidation may improve the composite internal closed-pack hexagonal columnar substructure adhesion. A thinner 3 mm thick specimen showed good high thermal gradient cyclic resistance

- Advanced turbine environmental barrier coated SA Tyrannohex composite systems showed excellent preliminary long-term durability performance in the environment fatigue tests up to 104 MPa (15 Ksi) and at 1482° C (2700° F) in air. Higher load fatigue tests still on-going to evaluate the coating and composite load capability at high temperatures.